Application of Hydrodynamics and Dynamics Models for Efficient Operation of Modular Mini-AUVs in Shallow and Very-Shallow Waters

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Award #: N00014-98-1-0151
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LONG-TERM GOALS

The long-term goal of this research is to contribute to efficient design and operation of mini Autonomous Underwater Vehicles (mini-AUVs) in wave-energetic shallow and very-shallow waters based on rigorous dynamic and hydrodynamic analyses and modeling of underwater vehicles.

OBJECTIVES

The objective of the research is to carry out nonlinear dynamics and hydrodynamics analyses of small and modular mini-AUVs and determine the vehicle-stability, -maneuverability and motion response for a range of missions, vehicle-configurations and sea states, and thereby contribute to improving the efficacy and reliability of modular AUVs.

APPROACH

[1] The hydrodynamic forces on the vehicle are determined by solving the governing equations using finite-difference and boundary-integral algorithms. The PI is directly involved in the finite-difference analysis, while a graduate student in the hydrodynamic analysis based on the boundary-element method. The forces are computed for a range of parameters corresponding to vehicle configurations and sea states.

[2] Knowing the hydrodynamic forces and propeller thrust, the rigid-body equations of AUV motion are then solved to determine the vehicle stability, maneuverability and motion response in a given sea state. A senior-year research intern assisted the PI in the development of the numerical schemes for the solution of the equations of rigid-body motion and in the analysis of vehicle stability. Based on the hydrodynamics and dynamics simulations, optimal configuration and efficacy of the AUV in a given sea state can be determined prior to the mission.

[3] In order to validate and complement the numerical algorithms used for the determination of hydrodynamic forces, model tests are planned to be conducted at the SeaTech facility of Florida Atlantic University in the recently-completed wave-current tank equipped with PIV and force-measurement systems. Field measurement of vehicle motions will be used to assess the performance of the AUV hydrodynamics/dynamics model. One part-time graduate-student and one undergraduate-student

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2000**	2. REPORT TYPE	3. DATES COVERED **00-00-2000 to 00-00-2000**
4. TITLE AND SUBTITLE **Application of Hydrodynamics and Dynamics Models for Efficient Operation of Modular Mini-AUVs in Shallow and Very-Shallow Waters**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Department of Ocean Engineering,Florida Atlantic University,,777 Glades Road,,Boca Raton,FL,33431**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

assistants are involved in the experimental study. The AUV engineers and crew at Florida Atlantic University have conducted the field study on the AUV motions.

[4] Complementing the research on the vehicle dynamics, a hydrodynamics-based algorithm is developed to model the thrust and torque of the AUV propeller. The algorithm is based on the blade-element method with lift and drag coefficients of the blade sections specified from experimental data. The algorithm can be used for design of thrusters for the AUV. A senior-year undergraduate student has assisted the PI in the development of propeller algorithm.

WORK COMPLETED

The tasks completed during the year 2000 (as of September 2000) are as follows:

[1] A finite-difference algorithm is developed for modeling the hydrodynamics of an AUV advancing in a shallow-water wave field.

[2] Hydrodynamic coefficients and forces on the *Morpheus* AUV, under unsteady motion in infinite fluid, are computed using the boundary-element method.

[3] Robust numerical algorithms are developed for the analysis of the equations of rigid-body AUV motions.

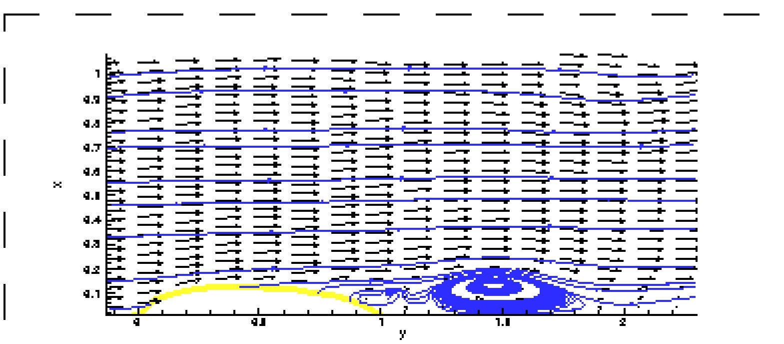
[4] Analytical and numerical investigations are carried out to determine the dynamic stability of *Ocean Explorer* (*OEX*) and *Morpheus* AUVs for a range of parameters such as forward speed, location of centers of gravity and buoyancy, fin geometry etc.

[5] Laboratory equipment are set up to conduct PIV measurements for flow about submerged bodies. Some preliminary results of flow structures are obtained for flow about submerged cylinders.

[6] A blade-element method based algorithm is developed for the design of thrusters for the *Morpheus* AUV.

[7] Field studies on *Morpheus* and *OEX* motions are to planned to carried out in October 2000.

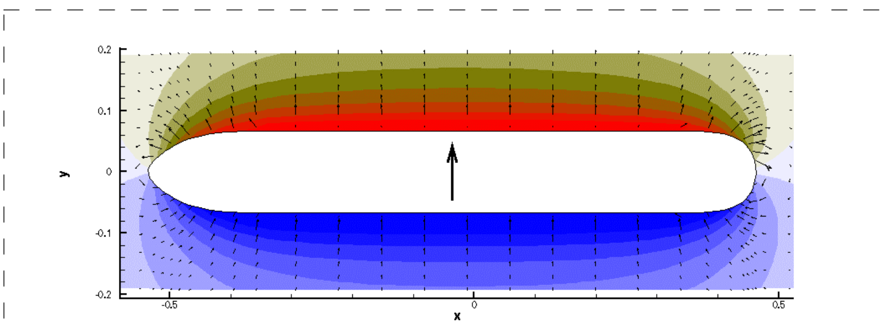
RESULTS



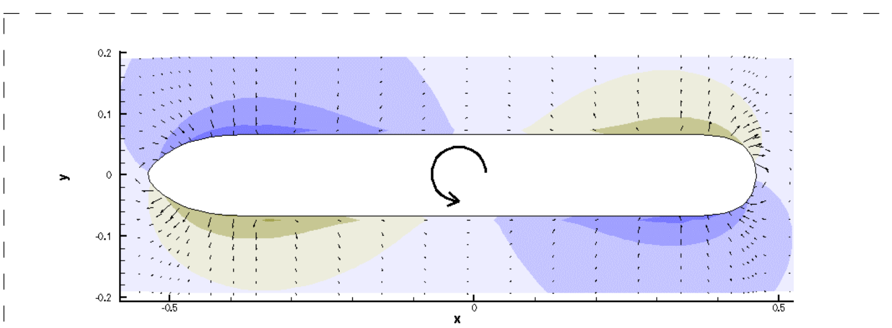
1: Instantaneous velocity field and streamlines for an AUV advancing in shallow-water waves.

[1] By solving the incompressible Navier-Stokes equations, the hydrodynamics of an AUV advancing in shallow-water waves is examined. For computational efficiency, the wave flow is modeled as an oscillating ambient current about the mini-AUV. The model is justifiable, as the AUV is small compared to the long shallow-water waves. The transport of vortices about the body (see, e.g., Fig.1 above), and hence the pressure force on the vehicle, are found to be dependent on the forward speed, depth of vehicle operation, water depth and the wave frequency. The results shed light on the interdependency of hydrodynamic forces and the evolution of vortex structures around the body in a wave field.

[2] Using the boundary-element method, the hydrodynamic flow about the Morpheus AUV, for all 6 DOF, has been analyzed. Figs.2 and 3 illustrate the computed velocity fields for a typical translation- and rotation-motion of the vehicle



2 Velocity-vector and –potential fields corresponding to heave translation of Morpheus AUV



3 Velocity-vector and –potential fields corresponding to pitch motion of Morpheus AUV

From the boundary-integral solutions, the hydrodynamic coefficients are also determined. The added-mass theory is used to compute the hydrodynamic force and moment on the vehicle. The computed forces are used in the dynamic analysis for the response of the vehicle.

[3] The dynamic stability of *OEX* and *Morpheus* AUVs under forward motion in midwater is analyzed by solving the equations of rigid-body motions using finite-difference method. Analytical solutions are obtained for validating the numerical algorithm. The hydrodynamic forces are determined using the boundary-integral solution and the added-mass theory, discussed earlier. The forces of control surfaces are modeled using experimental data. Based on the simulations, improvements to vehicle configurations

and design of control surfaces are suggested. For example, it is found that adding another module to the present configuration could improve the directional stability of the *Morpheus* AUV. It is also found that having a hinged-rudder will contribute to the improvement of the open-loop stability of the *Morpheus* AUV. The algorithm is also of use in determining the efficacy of the *Morpheus* and *OEX* AUVs under particular payload configuration in a given sea condition, prior to the mission. The details of the formulation, analysis and results are given in the technical report by Ananthakrishnan and Decron [1].

IMPACT/APPLICATIONS

[1] The viscous flow analysis of an AUV in shallow waters contributes to a better understanding of the fundamental physics of nonlinear wave-body interactions which is essential for the development of free-surface turbulence models.

[2] By concurrently carrying out the inviscid-flow analysis, we contribute to a better understanding of the importance of viscosity effects in marine hydrodynamics problems.

[3] By carrying out the dynamics simulation, we are able to identify the key mechanisms affecting and contributing to marine-vehicle stability. The analysis thus contributes to the development of optimal vehicle controllers.

TRANSITIONS

[1] The hydrodynamic coefficients and the dynamics analysis have been transitioned to the AUV researchers Drs Smith and An of Florida Atlantic University who are involved in the development of vehicle-controllers and -simulations.

[2] The propeller algorithm is of use in the design of propellers for the *Morpheus* AUV.

PUBLICATIONS

[1] P. Ananthakrishnan and S. Decron, ``Dynamics of Small- and Mini-Autonomous Underwater Vehicles: Part 1. Analysis and Simulation for Midwater Applications,'' *Technical Report*, 63 p., Department of Ocean Engineering, Florida Atlantic University, FL 33431, July 2000.

[2] C. Puaut, S. Decron, T. VanZwieten and P. Ananthakrishnan, ``Hydrodynamics and Dynamics Analysis of Modular Mini-AUV *Morpheus*,'' (to be submitted).